INTERNAL ANTENNA AND FLAT PANEL SPEAKER ASSEMBLIES AND MOBILE TERMINALS INCLUDING THE SAME

FIELD OF THE INVENTION

The present invention relates to the field of communications, and, more particularly, to antennas and wireless terminals incorporating the same.

BACKGROUND OF THE INVENTION

Manufacturers and designers of personal electronic devices, such as cellular radio telephones, frequently seek to reduce the overall dimensions of such devices while maintaining attractive style characteristics for the devices. One consequence of the reduced size for such devices that include a speaker is that less space may be available for the speaker. Furthermore, a variety of audio signal generation capabilities may be desired in such personal electronic devices including buzzers, voice signal generation and/or music or other higher frequency band signal reproduction and playback.

As the space available for the hardware supporting the audio signal generation capabilities decreases in the personal electronic devices, it may become more difficult to support multiple sound emitting output devices, and the space available for each such device may become smaller. Furthermore, increased functionality in such personal electronic devices may require more of the reduced available space to be utilized for other functionality of the device. The reduction in the size of the audio output devices may also increase the difficulty of providing a desirable loudness level for signals, such as buzzer alert signals.

One way to meet the demand for a reduction in the size of personal electronic devices is to use flat-panel speakers in place of the conventional speakers. Flat-panel speakers vibrate air using a large, thin conductive diaphragm panel, rather than the traditional cone-shaped panel, and, therefore, require less space.

There is also an interest in small antennas that can be utilized as internally mounted antennas for wireless terminals. Planar inverted-F antennas (PIFA's), for

example, may be well suited for use within the confines of wireless terminals, particularly wireless terminals undergoing miniaturization with a desire for increasingly larger displays. Typically, conventional PIFA's include a conductive element that is maintained in a spaced apart relationship with a ground plane. Exemplary PIFA's are described in U.S. Patent Nos. 6,166,694 and 6,353,443, which are incorporated herein by reference in their entirety.

Conventionally, PIFA configurations have branched structures such as described in U.S. Patent No. 5,926,139, and position the PIFA a suitable distance, typically from about 5-10 mm, from the ground plane to radiate effectively. Kin-Lu Wong, in *Planar Antennas for Wireless Communications*, Ch.1; p. 4, (Wiley, Jan. 2003), illustrates some potential radiating top patches for dual-frequency PIFAS. The contents of each of these references are hereby incorporated by reference in their entirety herein.

Despite the foregoing, there remains a need for improved and/or alternative speaker and antenna configurations.

SUMMARY OF THE INVENTION

Embodiments of the present invention provide internal antennas and flat-panel speakers for communications devices and wireless terminals. Embodiments of the invention include an integrated planar antenna and flat-panel speaker. Thus, for example, the planar antenna and the flat-panel speaker can be formed on a common substrate.

Certain embodiments are directed to an antenna subassembly. The antenna subassembly includes: (a) a planar antenna; and (b) a flat-panel speaker that is integrated with the planar antenna. In particular embodiments, the flat-panel speaker is configured to act as a parasitic element to the planar antenna. Thus, for example, the flat-panel speaker can be configured to provide a lower frequency range, an increased bandwidth, and/or a multi-band frequency response for the planar antenna, as compared to the frequency response of the planar antenna alone.

Other embodiments are directed to a wireless terminal. The wireless terminal includes: (a) a housing; (b) an electronic circuit disposed within the housing; (c) a flat-panel speaker proximate a back side of the electronic circuit within the housing; and (d) an internal antenna proximate the flat-panel speaker on the back side of the electronic circuit within the housing. In certain embodiments, the planar antenna and

the flat-panel speaker are merely co-located adjacent each other on the same side of the electronic circuit, while in others they are integrated into a common body or substrate.

In particular embodiments, the housing of the wireless terminal includes an earpiece and a keyboard on its front face, and the electronic circuit is positioned between the front face of the housing and the flat-panel speaker. In such embodiments, therefore, the wireless terminal further includes a forward acoustic passageway that extends from the flat-panel speaker to the earpiece and includes at least one acoustic aperture extending through the electronic circuit adjacent the flat-panel speaker.

In certain embodiments, the electronic circuit of the wireless terminal includes an audio driver circuit in communication with the flat-panel speaker. In other embodiments the audio driver circuit is coupled through a balanced feed to the flat-panel speaker. In still other embodiments, the balanced feed includes a plurality of leads with an RF isolation circuit on each lead. Thus, for example, the balanced feed can include a tank circuit and/or an inductor on each lead of the balanced feed.

These and other embodiments will be described further below.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is an exploded perspective view of a wireless terminal device according to embodiments of the present invention.

Figures 2A-2C are the top, bottom and side view, respectively, of a flat-panel speaker according to embodiments of the present invention.

Figures 3A-3D are side views of exemplary planar antenna and a flat-panel speaker subassemblies according to embodiments of the present invention.

Figures 4A-4C are simulated graphs of Voltage Standing Wave Ratios illustrating exemplary frequency responses of a planar antenna according to embodiments of the present invention.

Figures 5 and **6** are schematic block diagrams illustrating exemplary components of an electronic circuit and connections between the components and the planar antenna and/or flat-panel speaker according to embodiments of the present invention.

Figures 7A-7C are schematic block diagrams illustrating exemplary couplings between an audio driver circuit and a flat-panel speaker according to embodiments of the present invention.

Figure 8A is a top view of an exemplary flat-panel speaker integrated with a planar antenna.

Figure 8B is a cross section side view of the exemplary flat-panel speaker integrated with a planar antenna shown in **Figure 8A**.

Figures 9A-9E are cross section side views of exemplary substrate bodies integrating a flat-panel speaker and a planar antenna.

DETAILED DESCRIPTION

The present invention will now be described more fully hereinafter with reference to the accompanying drawings, in which embodiments of the invention are shown. This invention may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the invention to those skilled in the art. Like numbers refer to like elements throughout. It will be appreciated that although discussed with respect to a certain antenna embodiment, features or operation of one antenna embodiment can apply to others.

In the drawings, the thickness of lines, layers, features, components and/or regions may be exaggerated for clarity. It will be understood that when a feature, such as a layer, region or substrate, is referred to as being "on" another feature or element, it can be directly on the other element or intervening elements may also be present. In contrast, when an element is referred to as being "directly on" another feature or element, there are no intervening elements present. It will also be understood that, when a feature or element is referred to as being "connected" or "coupled" to another feature or element, it can be directly connected to the other element or intervening elements may be present. In contrast, when a feature or element is referred to as being "directly connected" or "directly coupled" to another element, there are no intervening elements present. However, it is noted that the presence of a coating or film layer on a substrate does not exclude the conductive element from being "directly formed" on the substrate albeit over the coating or film thereon.

The terms "comprises, comprising" and derivatives thereof, means that the recited feature, operation, integer, component, step, and the like is present but does not exclude or preclude the presence or addition of one or more alternative or different features, integers, steps, components or groups.

As used herein, the term "wireless terminal" may include, but is not limited to, a cellular wireless terminal with or without a multi-line display; a Personal Communications System (PCS) terminal that may combine a cellular wireless terminal with data processing, facsimile and data communications capabilities; a PDA (personal digital assistant) that can include a wireless terminal, pager, internet/intranet access, web browser, organizer, calendar and/or a GPS receiver; and a conventional laptop and/or palmtop receiver or other appliance that includes a wireless terminal transceiver. Wireless terminals may also be referred to as "pervasive computing" devices and may be mobile terminals including portable radio communication equipment. The term "portable radio communication equipment" (which can also be referred to interchangeably as "a mobile radio terminal") includes all portable equipment such as mobile telephones, pagers, and communicators, including, but not limited to, smart phones, electronic organizers, and the like.

It will be understood by those having skill in the art of communications devices that an antenna is a device that may be used for transmitting and/or receiving electrical signals. During transmission, the antenna may accept energy from a transmission line and radiate this energy into space. During reception, the antenna may gather energy from an incident wave and provide this energy to a transmission line. The amount of power radiated from or received by an antenna is typically described in terms of gain.

Embodiments of the present invention will now be described in detail below with reference to the figures. **Figure 1** is an exploded perspective view of a wireless terminal **100**. As illustrated, the wireless terminal **100** includes a front face **110f** and a back face **110b** that mate to define a portable housing of the wireless terminal **100**. The wireless terminal **100** includes an electronic circuit **120**, a flat-panel speaker **130** and an internal antenna **140** that are positioned within the housing. The internal antenna **140** is typically a planar antenna **140** and configured as a PIFA, a single-contact patch antenna, or a bent monopole antenna. Although certain embodiments are described with respect to a planar inverted-F antenna, the antenna may not be

strictly "planar" although in the vernacular of the art, it might still be referred to as a planar inverted-F antenna.

In addition, the electronic circuit **120** of the wireless terminal **100** may comprise a printed circuit board (PCB) having a signal feed and ground plane wherein the planar antenna **140** is operatively coupled to the signal feed and ground plane of the PCB. It will be understood that although the term "ground plane" is used throughout the application, the term "ground plane", as used herein, is not limited to the form of a plane. For example, the "ground plane" may be a strip or any shape or reasonable size and may include non-planar structures such as shield cans or other metallic objects.

As shown in **Figure 1**, the front face **110f** of the housing includes an earpiece **115** and a keypad **117**. The electronic circuit **120** is positioned between the front face **110f** and the back face **110b** of the housing. The flat-panel speaker **130** and the planar antenna **140** are held in the housing so that they are both between the back side of the electronic circuit **120b** and the back face of the housing **110b**. The flat-panel speaker **130** and the planar antenna **140** may be disposed on separate substrates, as shown, or they may be integrated, for example, by using a common substrate, as will be discussed further below. In position, the earpiece **115** outputs acoustic signals/sound from the speaker to a user.

Figures 2A-2C show the top, bottom and side views of a conventional flat-panel speaker **130**. As illustrated, the flat-panel speaker **130** is a substantially planar element that comprises a conductive pattern **130p**, leads **135**, **137** for communicating with the electronic circuit **120** and a thin diaphragm panel component **139** that provides an acoustic response to an input signal. The diaphragm component **139** may be a divided diaphragm panel and may be formed of a pieza electric material, such as pieza ceramic. The terms "lead" and "trace" are used interchangeably throughout to indicate electrical paths.

An exemplary flat-panel speaker configured for use in personal electronic devices can be obtained from Panasonic, distributed by DigiKey located in, South Theif River Falls, Minnesota called a "card-type speaker" with part no. WM R03B. The Panasonic card-type speaker features an ultra-thin, ultra-light pieza ceramic divided diaphragm. The two-way mechanical structure of the divided diaphragm, combining one large speaker for low-frequency sounds with four small speakers for high-frequency sounds makes broad-spectrum audio reproduction possible. In

addition, the vibrating membrane can be covered with a high polymer coating to protect against dampness, dust and corrosion.

Figures 3A-3D illustrate exemplary locations where the flat-panel speaker **130** can be placed with respect to the electronic circuit **120** and the planar antenna **140**. As shown, the flat-panel speaker **130** and the planar antenna **140** can be positioned proximate each other on the back side **120b** of the electronic circuit **120**. Because of this positioning, at least one acoustic aperture can be formed in the PCB, or electronic circuit, to define a forward acoustic passageway **305** that extends from the flat-panel speaker **130** to the front side **120f** of the electronic circuit **120**. Thus, to guide the acoustic output to the earpiece (**115 Figure 1**) in order to reduce acoustic interference during operation, at least one acoustic aperture **125** can be formed so that it extends through the electronic circuit **120**. The direction of the acoustic output is indicated in **Figures 3A-3D** by the broken-line arrow. In the case where the planar antenna **140** is positioned between the flat-panel speaker **130** and the electronic circuit **120**, as illustrated in **Figure 3C**, at least one acoustic aperture **145** extending through the planar antenna **140** is also created. The direction of the forward acoustic passageway **305** is illustrated by the broken-line arrow extending from the flat-panel speaker **130** through the electronic circuit **120**. The wireless terminal could also include an enclosed acoustic channel, not shown, that may be used to guide the acoustic output for improved signal clarity.

As shown in **Figure 3A** the flat-panel speaker **130** can be a separate component from the antenna **140** and placed between the planar antenna **140** and the electronic circuit **120** so that it abuts the planar antenna **140**. **Figure 3B** illustrates that the flat-panel speaker **130** can be integrated with the planar antenna **140** to create an integrated flat-panel speaker/planar antenna **800**, as will be discussed further with respect to **Figures 8** and **9**.

Figures 3C and **3D** show that the flat-panel speaker **130** can be offset with a lateral or transverse gap space **131** separating it from the planar antenna **140**. The planar antenna **140** may be placed between the flat-panel speaker **130** and the electronic circuit **120**, as shown in **Figure 3C**. **Figure 3D** illustrates that the flat-panel speaker **130** may be positioned between the planar antenna **140** and the electronic circuit **120** and offset in the longitudinal direction so that it is below or above (not shown) the planar antenna **140**. In addition, although not shown, the planar antenna **140** can be positioned closer to the flat-panel speaker **130** then

longitudinally offset therefrom. The term "proximate" means that the flat-panel speaker **130**, and the planar antenna **140** are spatially aligned on a common side of the electronic circuit **120** within the housing typically so that a portion of the flat-panel speaker **130** overlies the planar antenna **140**, or vice versa.

By positioning, configuring and/or electrically connecting the flat-panel speaker **130** with respect to the planar antenna **140**, the flat-panel speaker **130** can be configured to function as a parasitic element to the planar antenna **140** in certain frequency ranges. **Figures 4A-4C** illustrate exemplary frequency responses of the planar antenna **140** according to various embodiments of the present invention. The graphs represent Voltage Standing Wave Ratios (VSWR's). VSWR relates to the impedance match of an antenna feed point with a feed line or transmission line of a communications device, such as a wireless terminal. To radiate radio frequency energy with minimum loss, or to pass along received RF energy to a wireless terminal receiver with minimum loss, the impedance of a wireless terminal antenna is conventionally matched to the impedance of a transmission line or feed point. Conventional wireless terminals typically employ an antenna that is electrically connected to a transceiver operatively associated with a signal processing circuit positioned on an internally disposed printed circuit board. In order to increase the power transfer between an antenna and a transceiver, the transceiver and the antenna may be interconnected such that their respective impedances are substantially "matched," *i.e.*, electrically tuned to compensate for undesired antenna impedance components, to provide a 50-Ohm (Ω) (or desired) impedance value at the feed point.

In **Figures 4A-4C**, the broken line **410** illustrates a simulated frequency response of a planar antenna **140** operating independent of the flat-panel speaker **130** and therefore being substantially unaffected by the flat-panel speaker **130**, while the solid lines **420a**, **420b** and **420c** illustrate an altered frequency response of a planar antenna **140** influenced by the contribution of the flat-panel speaker **130** when configured as a parasitic element. As shown in **Figure 4A**, the flat-panel speaker **130** can be configured and/or positioned with respect to the planar antenna **140 (Figure 1)** to provide a lower frequency range for frequency response **420a** for the planar antenna **140**. **Figure 4B** illustrates that the flat-panel speaker **130** can be configured to provide an increased bandwidth frequency response **420b**, while **Figure 4C**

illustrates that the flat-panel speaker **130** can be configured to provide a multi-band frequency response **420c**.

Figures 5 and **6** illustrate exemplary components in the electronic circuit **120** (the electronic circuit **120** is illustrated by the rectangular broken line) and connections between the components and the planar antenna **140** and/or flat-panel speaker **130** according to embodiments of the present invention. As shown in **Figure 5**, the electronic circuit **120** can include an antenna driver circuit **122** in electrical communication with the planar antenna **140** and an audio driver circuit **127** in electrical communication with the flat-panel speaker **130**. Exemplary signal compensation techniques of coupling the audio driver circuit **127** to the flat-panel speaker **130** are discussed with respect to **Figures 6** and **7A-7C** below.

As shown in **Figure 6**, the electronic circuit **120** can further include a signal compensation circuit **128**. In operation, the signal compensation circuit **128** detects when the antenna **140** is in transmit mode, *i.e.*, when it is accepting energy from a transmission line and radiating this energy into space. During a detected transmission, the signal compensation circuit **128** compensates the signal from the audio driver circuit **127** to the flat-panel speaker **130** to inhibit noise from being communicated by the flat-panel speaker **130**. The signal compensation circuit **128** can be any suitable signal processing circuit including hardware and/or software components as is known to those of skill in the art.

Figures 7A-7C illustrate that the audio driver circuit **127** of the electronic circuit **120** can be coupled to the flat-panel speaker **130** through a balanced feed. As is known to those of skill in the art, the term "balanced feed" refers to transmitting a differential signal over leads having positive and negative voltages, rather than leads representing signal and ground voltages, in order to reduce the susceptibility to noise either internally generated by the wireless terminal or external noise.

As shown in **Figure 7A**, the leads **135, 137** of the flat-panel speaker **130** may have a direct connection to the audio driver circuit **127**. Alternatively, an RF isolation circuit **135R, 137R,** comprising either an inductor **710, 715**, one on each lead **135, 137**, or a tank circuit **720,725** on respective leads **135** and **137**, may be used to couple the audio driver circuit **127** and the flat-panel speaker **130**, as shown in **Figures 7B** and **7C**. Other RF isolation circuit configurations may also be used as is known to those of skill in the art.

As shown in **Figure 8A**, certain embodiments of the invention include a planar antenna **140** that is "integrated" or "integral" with a flat-panel speaker **130** (referred to generally as integrated device **800**). The terms "integrated" or "integral" mean that the flat-panel speaker **130** and the planar antenna **140** are combined so that at least a portion of the planar antenna **140** is etched, printed or otherwise formed on, attached to, and/or supported by the substrate forming the flat-panel speaker **130**. The substrate **800s** may include a single layer or a plurality of layers.

Figure 8A illustrates that the conductive element **140e** of the planar antenna **140**, as well as the conductive pattern **130p** of the flat-panel speaker **130** can be formed on the first primary surface of the flat-panel speaker body **130b** and the substrate **800s** may include a single layer of material. **Figure 8** also shows antenna leads **801, 802** (*i.e.*, ground and signal paths) and flat-panel speaker leads **135, 137** on the integrated flat-panel speaker/planar antenna component **800**.

Figure 8B shows the cross section of the exemplary integrated flat-panel speaker/planar antenna component **800** shown in **Figure 8A**. As shown, the flat-panel speaker conductive pattern **130p** and diaphragm component **139** are formed on the first and the second primary sides of the single-layer substrate **800s**. The antenna conductive element **140e** is formed on the first primary side of the same substrate **800s**.

Figures 9A-9E illustrate that the substrate **800s** can be formed of one (**Figures 8** and **9A**) or a plurality (**Figures 9B-9E**) of material layers. Typically the layers **910, 920** and/or **930** are made from non-conductive material with conductive portions configured to define the planar antenna **140** and the flat-panel speaker **130**. The layers **910, 920** and/or **930** may be thin film or other substrate layers, typically less than 5mm thick, and more typically less than about 1mm, and more typically between about 0.2-0.5mm thick. **Figure 9A** shows substrate **800s** as a single layer **910** with a cutout or space **130c** to allow the diaphragm component **139** to flex. In embodiments where the substrate is made from a flexible material, a cutout **130c** may not be needed. As shown, the antenna conductive element **140e** may be formed on the first primary surface of the material layer **910**, while the speaker conductive pattern **130p** may be formed on the second primary surface.

Figures 9B and **9C** show substrate **800s** as two layers **910** and **920** with the antenna conductive element **140e** formed on a first primary surface of the first layer **910**. **Figure 9B** shows the speaker conductive pattern **130p** formed on the first

primary surface of the second layer **920**, while **Figure 9C** shows the speaker conductive pattern **130p** on the second primary surface of the second layer **920**. **Figures 9B** and **9C** also show a cutout **130c** to allow the diaphragm component **139** to flex. As shown in **Figure 9B,** the cutout **130c** can extend above and below the diaphragm component **139** to allow movement in either direction. **Figure 9B** further shows acoustic apertures **130a** extending through the second layer **920** to the second primary surface of the second layer **920** to allow for transmission of the acoustic signal.

Figures 9D and **9E** show substrate **800s** as three layers **910, 920** and **930** with the antenna conductive element **140e** on the first primary surface of the first layer **910**. **Figure 9D** shows the speaker conductive pattern **130p** formed on the first primary surface of the third layer **930**, while **Figure 9E** shows the speaker conductive pattern **130p** on the second primary surface of the third layer **930**. **Figures 9D** and **9E** also show a cutout **130c** to allow the diaphragm component **139** to flex, with the cutout **130c** of **Figure 9D** extending above and below the diaphragm component **139**. **Figure 9D** further shows acoustic apertures **130a** extending through the third layer **930** to the second primary surface of the third layer **930** to allow for transmission of the acoustic signal.

It will be understood that, although antennas according to embodiments of the present invention are described herein with respect to wireless terminals, embodiments of the present invention are not limited to such a configuration. For example, antennas according to embodiments of the present invention may be used within wireless terminals that may only transmit or only receive wireless communications signals. For example, conventional AM/FM radios or any receiver utilizing an antenna may only receive communications signals. Alternatively, remote data input devices may only transmit communications signals.

In the drawings and specification, there have been disclosed embodiments of the invention and, although specific terms are employed, they are used in a generic and descriptive sense only and not for purposes of limitation, the scope of the invention being set forth in the following claims. Thus, the foregoing is illustrative of the present invention and is not to be construed as limiting thereof. Although a few exemplary embodiments of this invention have been described, those skilled in the art will readily appreciate that many modifications are possible in the exemplary embodiments without materially departing from the novel teachings and advantages

of this invention. Accordingly, all such modifications are intended to be included within the scope of this invention as defined in the claims. In the claims, means-plus-function clauses, where used, are intended to cover the structures described herein as performing the recited function and not only structural equivalents but also equivalent structures. Therefore, it is to be understood that the foregoing is illustrative of the present invention and is not to be construed as limited to the specific embodiments disclosed, and that modifications to the disclosed embodiments, as well as other embodiments, are intended to be included within the scope of the appended claims. The invention is defined by the following claims, with equivalents of the claims to be included therein.